Micrometer-Scale Reliability:

Nanomagnetodynamic Imaging of Magnetic Domain Walls

The purpose is the development of high sensitivity, low noise magnetic sensors for use as metrological tools in health care, homeland security and general information technology. In health care, non-invasive sensors are needed for medical evaluation in the areas of magneto-cardiography and magnetic bead tracking of blood flow and stem cells. In homeland security sensors are needed to detect low levels of pathogens. In IT, sensors are needed for ND failure analysis and magnetic data storage, among others.

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The goal is to develop multi-level magnetic sensors with a sensitivity better than 1 p-tesla /√Hz at 1 Hz noise level that operate at room temperature and can be easily integrated with standard silicon electronics. This involves a many faceted program which includes materials development, sensor fabrication, sensor characterization, modeling and nanomagnetodynamic imaging. The component being studied here concerns the dynamic observation of magnetic domain walls using Lorentz microscopy in the transmission electron microscope. Imaging of static magnetic domain walls in the TEM is not new, but our focus is to study the dynamics of domain wall-defect interactions and changes in spin distributions associated with defects or other discontinuities in nanodevices. The ultimate goal is to associate the dynamical interactions with electrical noise measurements in the same sensor.

The magnetic domain wall imaging effort has just started. A 200kV TEM was obtained in 2003. A high resolution, high speed CCD camera was installed and high resolution dynamic magnetic imaging was successfully demonstrated. A sample holder with multiple current feed-throughs was designed which allows the application of magnetic fields for in-situ testing. Thus far we have obtained high resolution domain wall images at imaging speeds up to 15 frames/s. In particular, we have filmed the formation and movement of Bloch lines and points in cross-tie walls in 50nm thick Ni80Fe20 films, and we have observed the pinning of cross-tie walls at small defects in an non-crystalline CoFeNiSiB alloy film provided by a US magnetic sensor company. Both these dynamic experiments were performed by slowly varying the small local magnetic field in the neighborhood of the specimens in the TEM. Domain wall movement was possible since the coercivity of both films was very small, on the order of a few Oersteds.

The observation of pinning of the domain walls by small defects in the CoFeNiSiB film demonstrated our capability to view interactions in real time. Further, with frame-by frame analysis of the video, we determined which defects interacted with the domain walls. A few frames from a video sequence containing domain wall pinning are shown in Figure 1. High magnification images of the non-crystalline defects are given in Figure 2.

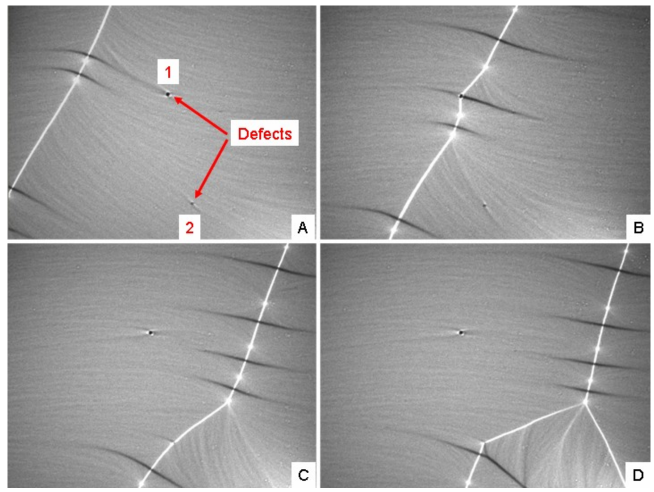

Figure 1. Images A to D are from a video sequence showing domain wall pinning. The cross-tie wall seen at the left hand side in A slowly moves to the right under the application of a small magnetic field in B through D. In B the wall is pinned by defect 1. With continued applied field the wall breaks free from defect 1 and moves to defect 2 where it is again pinned as suggested in C and definitely in D. Defects 1 and 2 are 4 micrometers apart.

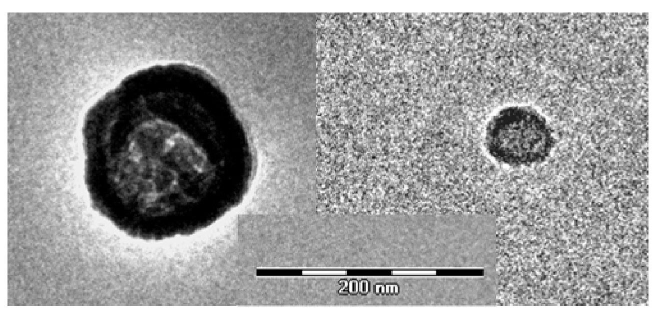

Figure 2. Images of the individual defects 1 and 2.

An abstract involving this work has been submitted to the 2004 Magnetism and Magnetic Materials conference. Studies on smaller structures are the next phase.

Contributors and Collaborators

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